Economics of 15 options for industrial utilization of poplars

W.J. Ondro

Northwest Region • Information Report NOR-X-320

Forestry Canada Forêts Canada

91-03948/

Forestry Canada's Northwest Region is responsible for fulfilling the federal role in forestry research, regional development, and technology transfer in Alberta, Saskatchewan, Manitoba, and the Northwest Territories. The main objectives are research and regional development in support of improved forest management for the economic, social, and environmental benefit of all Canadians. The Northwest Region also has responsibility for the implementation of federal–provincial forestry agreements within its three provinces and territory.

Regional activities are directed from the Northern Forestry Centre in Edmonton, Alberta, and there are district offices in Prince Albert, Saskatchewan, and Winnipeg, Manitoba. The Northwest Region is one of six regions and two national forestry institutes of Forestry Canada, which has its headquarters in Ottawa, Ontario.

Forêts Canada, région du Nord–Ouest, représente le gouvernement fédéral en Alberta, en Saskatchewan, au Manitoba et dans les Territoires du Nord–Ouest en ce qui a trait aux recherches forestières, à l'aménagement du territoire et au transfert de technologie. Cet organisme s'intéresse surtout à la recherche et à l'aménagement du territoire en vue d'améliorer l'aménagement forestier afin que tous les Canadiens puissent en profiter aux points de vue économique, social et environnemental. Le bureau de la région du Nord–Ouest est également responsable de la mise en oeuvre des ententes forestières fédérales–provinciales au sein de ces trois provinces et du territoire concerné.

Les activités régionales sont gérées à partir du Centre de foresterie du Nord dont le bureau est à Edmonton (Alberta); on trouve également des bureaux de district à Prince Albert (Saskatchewan) et à Winnipeg (Manitoba). La région du Nord–Ouest correspond à l'une des six régions de Forêts Canada, dont le bureau principal est à Ottawa (Ontario). Elle représente également deux des instituts nationaux de foresterie de ce Ministère.

ECONOMICS OF 15 OPTIONS FOR INDUSTRIAL UTILIZATION OF POPLAR

W.J. Ondro

INFORMATION REPORT NOR-X-320

FORESTRY CANADA
NORTHWEST REGION
NORTHERN FORESTRY CENTRE
1991

© Minister of Supply and Services Canada 1991
Catalogue No. Fo46-12/320E
ISBN 0-662-18680-X
ISSN 0704-7673

This publication is available at no charge from:
Forestry Canada
Northwest Region
Northern Forestry Centre
5320 – 122 Street
Edmonton, Alberta
T6H 3S5

A microfiche edition of this publication may be purchased from:
Micromedia Ltd.
Place du Portage
165, Hôtel-de-Ville
Hull, Quebec
J8X 3X2

Printed in Canada

The inside of this report has been printed on recycled paper.

Ondro, W.J. 1991. *Economics of 15 options for industrial utilization of poplars.* For. Can., Northwest Reg., North. For. Cent., Edmonton, Alberta. Inf. Rep. NOR-X-320.

ABSTRACT

Fifteen options were studied to assess their economic feasibility in the industrial utilization of poplar by mills producing dimension lumber, veneer, and particle board. The results of these studies are discussed in terms of harvesting, product recovery and cost, energy and labor requirements, projected financial returns, investment possibilities, and other variables. Detailed information and comparisons are presented in numerous tables.

RÉSUMÉ

15 options différentes ont été étudiées afin de déterminer s'il était économiquement faisable que les usines produisant des débits de dimensions specifiées, des placages et des panneaux de particules utilisent de façon industrielle le bois de peuplier. Les résultats de ces études sont examinées en fonction de la récolte, du taux de récupération du produit et des besoins en matière d'énergie et de ressources humaines et financières, des rendements projetés, des possibilités d'investissement et autres variables. Les nombreux tableaux du rapport présentent des comparaisons et des données détaillées.

FOREWORD

ENFOR (ENergy from the FORest) is a contract research and development (R&D) program managed by Forestry Canada. It is aimed at generating sufficient knowledge and technology to realize a marked increase in the contribution of forest biomass to Canada's energy supply. The program was initiated in 1978 as part of a federal interdepartmental initiative to develop renewable energy sources.

The ENFOR program deals with biomass supply matters such as inventory, growth, harvesting, processing, transportation, environmental impacts, and socioeconomic impacts and constraints. A technical committee oversees the program, developing priorities, assessing proposals, and making recommendations. Approved projects are generally carried out under contract.

General information on the operation of the ENFOR program, including the preparation and submission of R&D proposals, is available upon request from:

The ENFOR Secretariat
Forestry Canada
Place Vincent Massey
351 St. Joseph Blvd.
Hull, Quebec
K1A 1G5

This report is based in part on ENFOR Project P-207, which was carried out under contract by Woodland Resources Services Ltd., Edmonton, Alberta (DSS File No. OSG.81-00012-01SG-KH 505-1-0136).

This work was supported in part by the
Federal Panel on Energy Research and Development (PERD).

CONTENTS

INTRODUCTION 1
Data Collection and Sources 1

POPLAR HARVESTING 1
Stand Description and Logging 1
Skidding, Loading, and Hauling 2
Scaling and Grading 2
Preparation of Logs in the Mills 2

RECOVERY OF WOOD PRODUCTS 4
Veneer and Plywood 4
Dimension Lumber and Studs 6
Waferboard and Oriented Strand Board 8

COSTS OF PRODUCTION 8
Delivered Wood Costs 9
Milling Costs 9

CONVERSION OF LOGGING AND MILL RESIDUES TO ENERGY 14
Heating Value of Mill Residues 14
Capital Costs for Integrated Energy Residue Conversion Plants 14
Utilization of Wood Residues and Marketing of Energy from Power Generating Plants 15
Comparison of Energy and Labor Needs for Integrated Options 16

ECONOMICS OF POPLAR UTILIZATION OPTIONS 17
Financial Returns 17
Sensitivity Analyses 17
Financial and Earning Projections 23
Investment Requirements and Sources 25

SUMMARY 25

ACKNOWLEDGMENTS 27

REFERENCES 27

APPENDIXES

1. Selected metric (SI) units and conversion factors 29
2. Wood residue energy conversion systems 30
3. Energy sources and prices 33

FIGURES

1. Scaling of poplar logs from an overmature stand on a landing 3
2. Poplar veneer and plywood produced and used extensively elsewhere in Canada 5
3. Slowly air-dried or kiln dried poplar dimension lumber suitable for the majority of construction and industrial uses 6
4. Oriented strand board used in the construction of furniture, walls, roofing, and flooring 11
5. Delivered wood costs for poplar and softwood logs in the Edson, Grande Prairie, and Slave Lake regions of Alberta, 1987 11
6. Poplar nonmerchantable material and mill residues used for energy production 16

TABLES

1. Characteristics of the three harvested poplar stands 2
2. Scaling summary of logs from the three poplar stands 2
3. Summary of peeler logs from the three poplar stands 2
4. Percentage recovery of wood products from the total net volume of the three poplar stands 4
5. Veneer weight and volume recovery of logs from the three poplars stands 5
6. Dimension lumber, weight, and volume recovery of logs from the three poplar stands 7
7. Dimension lumber product recovery from the three poplar stands 8
8. Number of pieces of dimension lumber by grade recovered from logs from the three poplar stands 9
9. Number of pieces of planed stud lumber by grade recovered from logs from the three poplar stands 10
10. Waferboard weight and volume recovered from logs from the three poplar stands 10
11. Capital and operating costs for 15 nonintegrated and energy-integrated mills producing poplar products . . 12
12. Additional capital costs for an integrated energy residue conversion plant 15
13. Wood inputs, energy, and labor requirements for 15 nonintegrated and energy-integrated mills producing poplar products 18
14. Average annual f.o.b. mill prices of spruce–pine–fir and poplar wood products for 1981–90 and predictions for 1991–93 20

15. Projected profit and loss statement for 15 nonintegrated and energy-integrated mills producing poplar products for the first 20 years of operation (in MM $) 21

16. Key assumptions for calculations of capital expenditures, operating revenues, and rates of return 23

17. Internal rate of return for 15 nonintegrated and energy-integrated mills producing poplar products 24

18. Sensitivity analysis of internal rate of return to changes in manufacturing costs and exchange rates for a nonintegrated oriented strand board mill and a waferboard mill 24

19. Financing investment needed for 15 nonintegrated and energy-integrated mills producing poplar products 26

NOTE

The exclusion of certain manufactured products does not necessarily imply disapproval nor does the mention of other products necessarily imply endorsement by Forestry Canada.

INTRODUCTION

This report addresses the opportunities for industrial utilization of poplar in Alberta, where trembling aspen (*Populus tremuloides* Michx.), balsam poplar (*P. balsamifera* L.), and black cottonwood (*P. trichocarpa* Torr. & Gray) accounted for 33% of the growing stock in 1991, but represented only about 25% of the volume harvested. In 1990–91, the opening of several new mills and higher production in existing mills greatly increased the use of poplar (mainly aspen) in the manufacture of pulp and paper. This species group was still underutilized, however, and its market potential underdeveloped (especially for high-value-added products), for two main reasons: 1) the relative abundance of softwoods in Alberta, and 2) insufficient general knowledge of the economic feasibility and profitability of poplar utilization for lumber, particle board, plywood, and energy.

The information in this report comes from a field study that involved the harvesting of three poplar stands (old, mature, and young) near Slave Lake, Alberta, during the winter of 1982. The stem-length and whole trees harvested were transported to dimension lumber, veneer, and waferboard mills in the Mitsue Industrial Park near Slave Lake; there the wood was graded for quality, and then processed into 1) veneer, 2) dimension lumber and studs, 3) waferboard or oriented strand board, and 4) mill residues for energy production.

In this report, economic analyses of poplar utilization are based on statistics of the actual recovery of wood products and energy from the poplar stands harvested near Slave Lake. The corresponding study of economic feasibility, using 1986–87 manufacturing costs and product prices, has three main objectives:

1. to evaluate the technological aspects and resulting costs of harvesting poplar in winter;

2. to determine the optimum recovery, in economic terms, of poplar wood products and energy from old (100-year), mature (80-year), and young (50-year) stands;

3. to evaluate and compare the economics of 15 options for the industrial utilization of poplar by plants with varying capabilities, including energy generation.

Data Collection and Sources

Poplar harvesting costs were obtained from logging contractors, the information on recovery of wood products was obtained from an ENFOR (ENergy from the FORest) field study by Woodland Resource Services Ltd. (1982) and from poplar product manufacturers, and the capital costs of mills were obtained from suppliers and distributors of plant machinery and equipment. Market overview data and product prices were obtained from Statistics Canada (1981–87), Widman Management Ltd. (1985–91), Woodbridge, Reed and Associates Ltd. (1985), Random Lengths Publications Inc. (1987–91), product retailers, and other sources.

POPLAR HARVESTING

Stand Description and Logging

The poplar stands selected for logging were located in Management Unit S-5 of the Slave Lake Forest, about 45 km east of Slave Lake, Alberta. The stands (old, mature, and young) varied in size (Table 1), but at least one-quarter of the total required volume (600 m^3)[1] was harvested in each age class. Each stand was predominantly trembling aspen and had a small percentage of balsam poplar, which was somewhat higher in the young stand.

A local contractor with experience in hardwood logging used chain saws in January 1982 to harvest the stands to 13-cm stumps and 10-cm top diameters. The majority of the trees were topped and limbed before loading, but about one-sixth of the volume in each stand was transported to the

[1] Appendix 1 gives selected metric conversions.

Table 1. Characteristics of the three harvested poplar stands

Parameter	Stand		
	Old	Mature	Young
Average age (yr)	100+	82	56
Area (ha)	0.77	0.68	0.76
Number of trees per ha	742	1424	1153
Gross volume (m^3)	238	217	158
Species composition (%)			
Aspen	98	98	90
Balsam poplar	2	2	10
Cull by volume (%)			
Aspen	13.4	6.5	18.4
Balsam poplar	1.3	0.9	1.3

mills as whole trees (including branches). The limbing and topping residues at the mill yard were used to estimate the logging residue available for generation of energy. The large tree size and open-grown condition made harvesting easier in the old stand, but it took two to three times longer to fell, limb, and top the old stand. Breakage of large branches and tops during felling, skidding, and decking occurred in all stands but especially in the old stand, partly because of the very cold temperature (–30°C) and the high incidence of decay. Breakage of branches and tops can hardly be avoided when harvesting by chain saw; however, it can be minimized in mechanized harvesting.

Skidding, Loading, and Hauling

Skidding was done by a 1980 Clark Ranger 664C equipped with a 73 kW engine and a winch. Average skidding distances were shortest in the old stand. Some difficulties were experienced with skidding of smaller trees in the mature stand, where chokers were hard to set and thus production was reduced. Piling of felled trees with skidders improved skidding production but resulted in some stem breakage and loss of branches.

Loading of the wood from all three stands was done by a 1978 Prentice heel-boom loader with a lift capacity of 2300 kg, mounted on a GMC 6500 flatbed truck. The average hauling distance between the stands and the mills was 47 km.

Scaling and Grading

Stem butt diameters were tallied in cold decks for each stand, and volumes were calculated using local volume tables (Alberta Energy and Natural Resources 1982). Wood from each stand was color-coded to identify its source and was weighed before processing. A sample of one-third of the loads hauled was used in the weight scaling. All loads were spread, bucked into 2.6-m log lengths, and scaled (Alberta Energy and Natural Resources 1979) in the yard. The cull in the young aspen was 18.4% by volume, but in the mature aspen it was only 6.5% (Table 1). The net stem weight (excluding limbs and tops) of the hauled tree-length logs was 213 540 kg in the old stand and 150 000 kg in the young stand (Table 2). The gross conversion factor for stem wood of 897 kg/m^3 in the old stand was the lowest for the three stands. The total net volume was about equal in the old and mature stands, whereas the young stand had about 60% of the volume of the other two stands.

Peeler logs and sawlogs were scaled (Fig. 1), graded, and sent for processing in the veneer-stud mill complex. Peeler logs had to be straight and free from large knots, cracks, and catfaces, and to have a minimum small-end diameter of 22 cm. Logs of exceptional quality with a small-end diameter down to 18 cm were also included. The potential peeler log contents were 35.4% (old stand), 19.1% (mature stand), and 16.9% (young stand) by gross volume (Table 3).

Balsam poplar was about 10% of the peeler log volume. When the total log mix from the three stands was considered, approximately 24% of the gross volume qualified as potential peeler logs, which was one-half or less than that which can be obtained from similar coniferous stands.

Preparation of Logs in the Mills

All poplar logs for veneer and stud mills were delivered to their mill yards and weighed in

Table 2. Scaling summary of logs from the three poplar stands

Parameter	Stand		
	Old	Mature	Young
Total weight (kg)	213 540	197 100	150 100
Total gross volume (m^3)	238	217	158
Total net volume (m^3)	203	201	127
Gross conversion factor (kg/m^3)	899	906	946
Net conversion factor (kg/m^3)	1 047	980	1 181

Table 3. Summary of peeler logs from the three poplar stands

Parameter	Stand		
	Old	Mature	Young
Number of trees	143	130	62
Sample load volume (m^3)	72.9	84.8	51.4
Gross volume of peelers (m^3)	25.7	16.2	8.7
Peeler volume from sample scale load (%)	35.4	19.1	16.9

Figure 1. Scaling of poplar logs from an overmature stand on a landing.

whole-tree lengths. They were then delivered to the infeed deck of the bucking line, where they were debarked and cut into 2.6-m bolts. The veneer bolts were prepared in steam-conditioning chests and were then placed onto the Coe lathe, where they were peeled to cores 14 cm in diameter and conveyed to the stud mill. Waferboard (WB) logs 13–51 cm diameter outside bark (dob) and oriented strand board (OSB) logs 10–69 cm dob were bucked into 2.6-m lengths in the stands and then were washed and debarked in the mill yards. These log sections were cut into 63-cm blocks for waferboard and 81-cm blocks for OSB and processed in the waferizers.

The main conversion unit in the stud sawmill was a 1.2-m scrag saw with four blades followed by a gang-saw edger. Lumber was air-dried. Grading and stacking of studs was done manually, and bundles were strapped. A sample of rough studs and dimension lumber at random lengths from each stand was weighed, air-dried, planed, graded, and trimmed for optimum lumber recovery. Green veneer from each stand was weighed, air-dried, graded, and trimmed to determine poplar veneer recovery. Calculations were made of mill residues from the conversion of logs to rough and planed lumber and veneer. Logging residues more than 2.5-cm dob were considered suitable for energy generation.

RECOVERY OF WOOD PRODUCTS

The poplar logs were delivered to a veneer–plywood mill, dimension lumber and stud mill, and waferboard mill. Logs delivered to the waferboard mill were also suitable for OSB production. The percentage recovery of wood products from the total net volume, by stand, is shown in Table 4.

Veneer and Plywood

Logs suitable for these products represented 24.0, 28.9, and 23.4% of the net volume of each of the three stands (old, mature, and young) delivered to the veneer and plywood mills (Table 5; Fig. 2). Ninety-one percent of the volume of 335 logs was processed by the veneer mill, while the remaining 9% was of small diameter and was processed in the dimension mill.

In the old stand only 9 out of 133 bolts were peeled to 14 cm, the minimum diameter for peelers. The remaining 124 logs were not peeled due to log defects such as interior butt rot, ring shake, and spiral grain. Fifty-one out of 121 logs from the mature stand and 3 of the 50 logs from the young stand were peeled to a 14-cm diameter. There was some butt rot in logs from mature and young stands; however, the major cause of partial peeling of these bolts was interior defects such as spiral grain, ring shake, and interior rot. The peeler logs were delivered to the log yard in February, but the peeling was done in May. Thawing frozen bolts in heating vats would cause poplar bolts to disintegrate in the veneer lathe.

The moisture content of aspen and other poplars varies by season, cull, and portion of the stem.

Table 4. Percentage recovery of wood products from the total net volume[a] of the three poplar stands

Parameter	Percentage recovery		
	Old	Mature	Young
Veneer	5.4	4.7	3.0
Dimension lumber	18.6	24.2	20.4
Studs[b]	30.0	29.0	25.0
Waferboard or oriented strand board	26.0	27.0	37.0
Energy residues and waste[c]	19.9	15.1	14.6
Total	100.0	100.0	100.0

[a] Cull excluded.
[b] Lumber recovered from residual veneer logs.
[c] Includes sawdust, small branches, and twigs.

Table 5. Veneer weight and volume recovery of logs from the three poplars stands

Parameter	Stand			
	Old	Mature	Young	Total
Weight of delivered green logs (kg)	65 520	71 360	48 620	185 500
Net green volume (m^3)	87.58	101.92	57.61	247.11
Green veneer logs scaled (No.)	143	130	62	335
Volume of green veneer logs scaled (m^3)	36.1	22.7	12.2	71.0
Green sawlogs scaled (No.)	366	1 003	634	2 003
Volume of green sawlogs scaled (m^3)	51.5	79.2	45.5	176.2
Green, veneer peeled 3/16-in. basis (M sq. ft.)	31.88	27.51	8.93	68.32
Green veneer logs peeled (No.)	133	121	50	304
Green veneer weight (kg)	3 500	3 080	860	7 440
Weight of rough green lumber (kg)	12 200	17 560	10 500	40 260
Moisture content[a] (%)	100	100	100	100
Relative density	0.375	0.375	0.375	0.375
Weight of residue following peeling and rough lumber (kg)	49 820	50 720	37 260	137 800
Ratio of weight of residue to weight of delivered logs (%)	76.0	71.1	76.6	74.3
Weight of lumber delivered to planer (kg)	2 920	2 800	2 940	8 660
Lumber volume delivered to planer (fbm)	1 717	1 717	1 717	5 151
Weight of planed lumber (kg)	1 380	2 080	1 740	5 200
Volume of planed lumber (fbm)	1 247	1 597	1 421	4 265
Green, veneer yield 1/16-in. basis (M sq. ft./m^3)	1.24	1.71	1.03	1.35
Recovery of rough lumber (fbm)	7 300	10 700	6 100	24 100
Veneer yield (%)	5.4	4.7	3.0	–[b]
Lumber recovery (%)	18.6	24.2	20.4	–
Average total recovery (%)	24.0	28.9	23.4	24.7

[a] Measured in the field and calculated by the following formula: $\%\ \text{moisture content} = \frac{\text{green weight - ovendry weight}}{\text{ovendry weight}} \times 100$

[b] Not applicable.

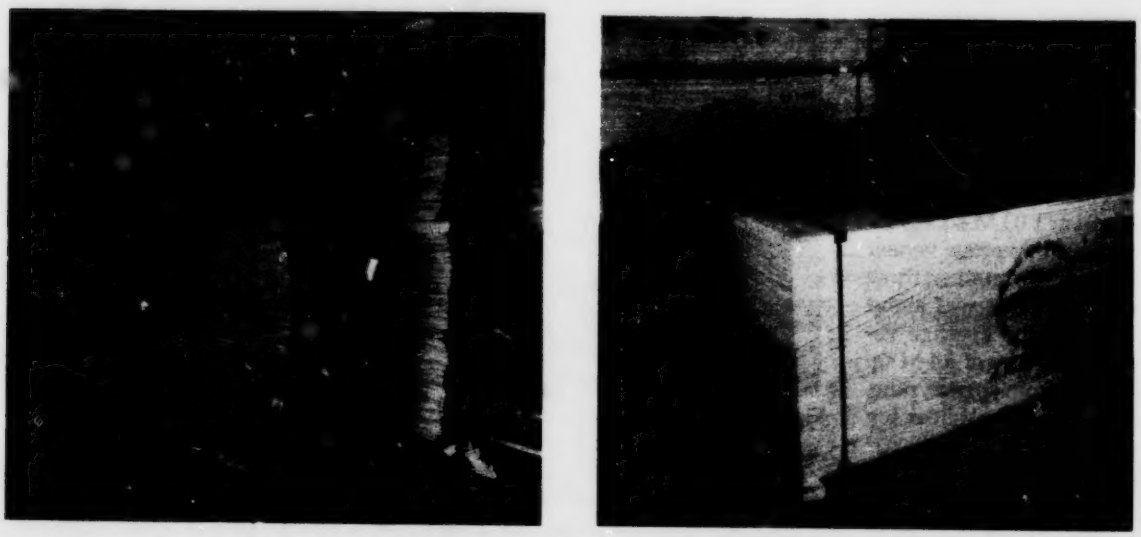

Figure 2. Poplar veneer and plywood are produced and used extensively elsewhere in Canada.

For fresh aspen logs the moisture content varies from 100 to 140% (U.S. Forest Service 1974; Haygreen and Bowyer 1982), with fresh aspen heartwood having a moisture content of 95% and sapwood 105% (U.S. Forest Service 1974). Forest industry sources[2] in Alberta suggest that fresh logs weigh about 975 kg/m^3 in winter and 900 kg/m^3 during summer. Logs with 10 and 25% cull weigh about 1025 and 1150 kg/m^3, respectively. Log weight with residual moisture of 3–5% varies from 380 to 460 kg/m^3.

The moisture content of fresh veneer logs (Table 5) was estimated from samples and calculated by the following equation (Mullins and McKnight 1981; Haygreen and Bowyer 1982):

$$\%\ moisture\ content = \frac{green\ weight - ovendry\ weight}{ovendry\ weight} \times 100$$

The average moisture content for a sample of fresh veneer logs was estimated at 100%. The relative density (formerly measured as specific gravity) needed to check the recovery of veneer and studs varied slightly, but an estimated value of 0.375 was used in calculations (Jessome 1977; U.S. Forest Service 1974).

Peeler log volume (veneer yield), as a percentage of total, was highest in the old stand at 5.4%, followed by the mature stand at 4.7%, and the young stand at 3.0%. The veneer recovery (1/16-in. basis) was highest from the mature stand at 1.71 M (thousand) sq. ft./m^3, followed by the old stand at 1.24 M sq. ft./m^3, and the young stand at 1.03 M sq. ft./m^3 (Table 5). Average veneer recovery from these three poplar stands was about one-half the average veneer recovery of 3.4 M sq. ft./m^3) from spruce, pine, and fir (SPF). Veneer log cores too small for peeling (14 cm in diameter and less) were used for studs. About 18.6, 24.2, and 20.4% of the total veneer log volume in (respectively) old, mature, and young stands were used for this product. Residues from the veneer and stud mill were log trims, slabs, edgings, end cut-offs, bark, sawdust, and shavings. The weight of these residues was calculated by subtracting the weight of the recovered products from the total weight of the peeler logs. Residues from veneer and stud mills were conveyed directly to the waste burner.

Dimension Lumber and Studs

Logs to be used as dimension lumber and studs were topped to 14 cm diameter; logs with excessive crook or sweep were bucked with a chain saw to recover the greatest volume of studs and dimension lumber (Fig. 3).

The volume of planed lumber recovered from logs was highest from the old stand at 179.2 foot board measure per cubic metre (fbm/m^3), followed by the mature stand volume at 172.2 fbm/m^3, and the young stand volume at 148.0 fbm/m^3. These figures represent about one-half the average provincial recovery for SPF (245 fbm/m^3), and

Figure 3. Slowly air-dried or kiln dried poplar dimension lumber suitable for the majority of construction and industrial uses.

[2] Personal communications from T. Nielsen of Weldwood of Canada Ltd., Hinton, Alberta, and N. Denney of Pelican Spruce Mills Ltd., now Weyerhaeuser of Canada Ltd., Edmonton, Alberta, August 1987.

convert to dimension lumber recovery factors of 42.5, 40.8, and 35.0% for the three stands, respectively (Table 6).

The recovery of 5-cm studs in all three stands was four to five times higher than the recovery of 2.5 cm dimension lumber (Table 7). While about one-half of the stud volume for old and mature stands was in studs 4.9 m long, the majority of studs in young stands were spread over lengths of 3.6, 4.3, and 4.9 m. Recovery of stud lumber of standard construction grade in the mature stand was three times higher than in the young stand and about one-third higher than in the old stand (Table 8). The recovery of studs of utility grade was highest in the old stand, but recovery of studs of economy grade was highest in the young stand. The average recoveries of aspen dimension lumber and studs combined were 53.2, 48.6, and 45.4%, respectively, for mature, old, and young stands (Table 4), which were considerably lower than the 93% average recovery from SPF studs of random length.

A sample of rough studs from each stand was planed to determine the best recovery. All of the 5 × 10 cm (2 × 4 in.) stud lumber was planed first; it was followed by 2.5×10 cm (1×4 in.) board lumber to reduce downtime required to reset the planer knives. The recovery of planed dimension lumber was highest from the mature stand, followed by the young and old stands (Table 9).

Slabs and edgings (85%), sawdust (8%), and planer shavings (7%) were the main residues from lumber and studs. Most residues, at 270.2 kg/m^3 ovendried weight, were obtained from the young stand, followed by residues from the old stand at 265.3 kg/m^3, and from the mature stand at 254.0 kg/m^3 (Table 6).

Heartwood rot was a major problem when sawing logs from the old stand, while crookedness was frequent in all three stands, resulting in delays and sawing difficulties on the log infeed deck and the headrig. Planing was also slow due to the high

Table 6. Dimension lumber, weight, and volume recovery of logs from the three poplar stands

Parameters	Stand		
	Old	Mature	Young
Weight of delivered green logs (kg)	70 720	73 060	49 260
Moisture content[a] (%)	82	82	104
Net green volume (m^3)	67.52	74.54	41.69
Ovendry weight of delivered logs (kg)	38 857	40 143	24 147
Relative density	0.411	0.385	0.414
Weight of rough green lumber (kg)	20 529	20 765	10 832
Volume of rough green lumber (fbm)	12 850	13 698	6 780
Ovendry weight of residue after sawing (kg)	27 605	28 762	18 830
Weight of planed lumber after 72 days of drying (kg)	13 726	14 188	7 248
Volume of planed lumber after 72 days of drying (fbm)	12 098	12 837	6 170
Moisture content after air-drying for 72 days (%)	75.4	44.9	44.9
Green weight of residue (kg)	6 803	6 577	3 584
Ovendry weight of residue after planing (kg)	3 878	4 538	2 473
Weight of ovendry residue per volume of green logs (kg/m^3)	333.1	333.4	365.0
Ovendry weight of lumber per volume of green logs (kg/m^3)	265.3	254.0	270.2
Volume of planed lumber per volume of green logs (fbm/m^3)	179.2	172.2	148.0
Full lumber recovery factor[b] (fbm/ft^3)	12.0	12.0	12.0
Actual lumber recovery factor (fbm/ft^3)	5.1	4.9	4.2
Relative lumber recovery factor (%)	42.5	40.8	35.0

[a] Measured in the field and calculated by the following formula: $\%\ \text{moisture content} = \frac{\text{green weight - ovendry weight}}{\text{ovendry weight}} \times 100$

[b] The volume and weight measurements were carried out in the field and therefore there is a high rate of marginal error.

Table 7. Dimension lumber product recovery from the three poplar stands

Stand	Length (ft.)	Sawmill				Planer			
		2 × 4 in. lumber		1 × 4 in. lumber		2 × 4 in. lumber		1 × 4 in. lumber	
		Number of pieces	Fbm	Number of pieces	Fbm	Number of pieces	Fbm	Number of pieces	Fbm
Old	8	119	634.6	81	216.0	256	1 365.2	102	272.0
	10	187	1 246.7	79	263.3	166	1 106.7	74	247.0
	12	217	1 736.0	85	340.0	207	1 656.0	62	248.0
	14	263	2 454.7	89	415.3	243	2 268.0	78	364.0
	16	469	5 002.3	88	469.3	382	4 074.4	80	426.7
	18	6	72.0	0	0.0	0	72.0	0	0.0
Total		1 261	11 146.3	422	1 703.9	1 260	10 542.3	396	1 557.7
Mature	8	87	463.9	0	0.0	148	789.3	129	344.0
	10	182	1 213.3	72	240.0	176	1 173.3	109	363.0
	12	220	1 760.0	98	392.0	202	1 616.0	92	368.0
	14	261	2 436.0	108	503.9	247	2 305.0	98	457.3
	16	470	5 013.0	110	586.7	420	4 479.7	163	869.3
	18	7	84.0	167	1 002.0	6	72.0	0	0.0
Total		1 227	10 970.2	555	2 724.6	1 199	10 435.3	591	2 401.6
Young	8	79	421.3	46	123.0	155	826.6	79	211.0
	10	149	993.3	76	253.3	140	933.3	76	253.3
	12	157	1 256.0	74	296.0	115	920.0	63	252.0
	14	153	1 428.0	56	261.3	113	1 055.0	41	191.3
	16	140	1 493.2	50	266.7	120	1 279.9	44	234.7
	18	3	36.0	0	0.0	1	12.0	0	0.0
Total		681	5 627.8	302	1 200.3	644	5 026.8	303	1 142.3

moisture content of the rough lumber, which caused the planer blowers to become plugged.

Waferboard and Oriented Strand Board

Waferboard recovery (3/8-in. basis) was higher from mature and young stands (471 and 515 sq. ft./m^3, respectively) than from old stands (465 sq. ft./m^3) (Table 10). In order to compare the waferboard recovery, wafer drying process, additives, and characteristics of the finished panel, waferboard specifications from several mills in North America were compared.

Poplar logs and mill residues were not processed for the OSB used by the furniture and construction industries (Fig. 4); it was assumed that the volume required for OSB would be equal to that processed for waferboard.

COSTS OF PRODUCTION

Costs and benefits for 15 integrated or nonintegrated mills were analyzed (Table 11). Seven options were single-product mills, and eight were integrated mills with generators producing their

Table 8. Number of pieces of dimension lumber by grade recovered from logs from the three poplar stands

Stand	Length (ft.)	2 × 4 in. lumber			1 × 4 in. lumber	
		Standard-construction	Utility	Economy	Standard-construction	Utility-economy
Old	8	66	93	97	74	28
	10	56	76	34	59	15
	12	68	101	38	53	9
	14	106	112	25	66	12
	16	207	165	10	72	8
	18	0	6	0	0	0
Total		503	553	204	324	72
Mature	8	64	45	39	95	34
	10	85	74	17	96	13
	12	108	74	20	81	11
	14	157	55	35	85	13
	16	306	105	9	156	7
	18	4	1	1	0	0
Total		724	354	121	513	78
Young	8	22	60	73	54	25
	10	49	48	43	59	17
	12	41	36	38	50	13
	14	47	27	39	33	8
	16	27	63	30	41	3
	18	0	1	0	0	0
Total		186	235	223	237	66

own energy. The costs of producing poplar wood products in Alberta, which include delivered wood costs and milling costs, were obtained from logging contractors and wood product plants in the Edson, Slave Lake, and Grande Prairie forests in 1987. The capital costs of buildings, plant machinery, and equipment were obtained from building contractors and equipment suppliers. Operating costs for 1987 were based on the actual recovery of products in 1982 and calculated using 1987 milling costs.

Delivered Wood Costs

Delivered wood costs increased with the transport distance from woods to mill; for example, an average delivered wood cost of $\$18.25/m^3$ was incurred at a distance of 70 km when harvesting the three poplar stands, as compared to a delivered wood cost of $\$18.75/m^3$ for softwoods (Fig. 5). The costs included stumpage ($\$0.25/m^3$, $\$1.07/M$ fbm), logging costs, transport of logs to the mill site, depreciation of logging and mobile equipment and trucks, road building and maintenance, capital borrowed to finance woodlands operations, and the cost of maintaining the log inventory in the yard.

Milling Costs

The cost of milling includes the capital cost of plant, plant machinery, and equipment for premanufacturing, processing of logs, and manufacturing operations. Further details on capital and operating costs are available from the author.

Logs delivered to the mill are subjected to different premanufacture processes, depending on the

Table 9. Number of pieces of planed stud lumber by grade recovered from logs from the three poplar stands

Parameters	Stand		
	Old	Mature	Young
Delivered to planer			
Number of pieces	322	322	322
Fbm	1717	1717	1717
Grade recovery (number of pieces)			
Stud	141	187	167
Economy	69	87	66
4-foot	17	13	14
5-foot	9	22	18
6-foot	13	7	20
Total	249	316	285
Fbm	1247	1597	1421

Table 10. Waferboard weight and volume recovered from logs from the three poplar stands

Parameters	Stand			
	Old	Mature	Young	Total
Weight of delivered green logs (kg)	77 300	52 680	52 220	182 200
Green bucking residue (kg)	4 040	13 380	12 380	29 800
Net green weight (kg)	73 260	39 300	39 840	152 400
Net volume of roundwood (m^3)	73.807	53.745	44.195	171.747
Estimated moisture content (%)	100.0	100.0	100.0	100.0
Net ovendried weight (kg)	36 630	19 650	19 920	76 200
Gross stacked green volume (m^3)	114.16	92.75	61.08	267.99
Cull deductions of stacked green volume (m^3)	5.92	2.19	2.11	10.22
Net stacked green volume (m^3)	108.24	60.24	58.97	227.45
Relative density	0.376	0.355	0.376	0.373
Gross volume of solid roundwood (m^3)	85.972	58.161	55.226	199.359
Bucking residue/net green weight (%)	5.5	34.0	31.1	19.6
Actual waferboard yield (sq. ft./m^3)	465	471	515	1 451
Relative waferboard yield (%)	26.0	27.0	37.0	–[a]

[a] Not available.

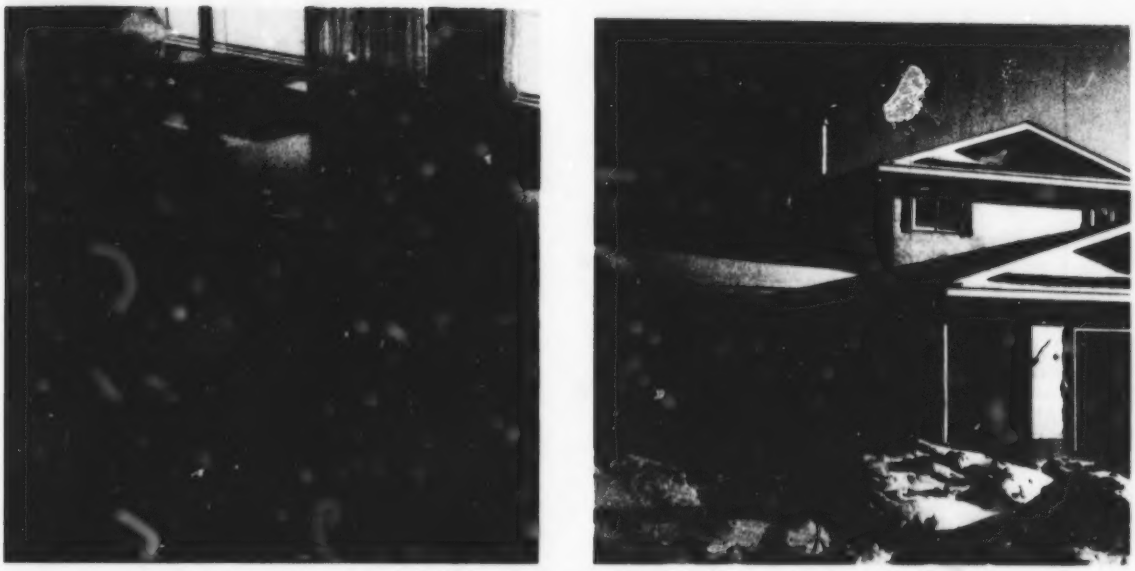

Figure 4. Oriented strand board used in the construction of furniture, walls, roofing, and flooring.

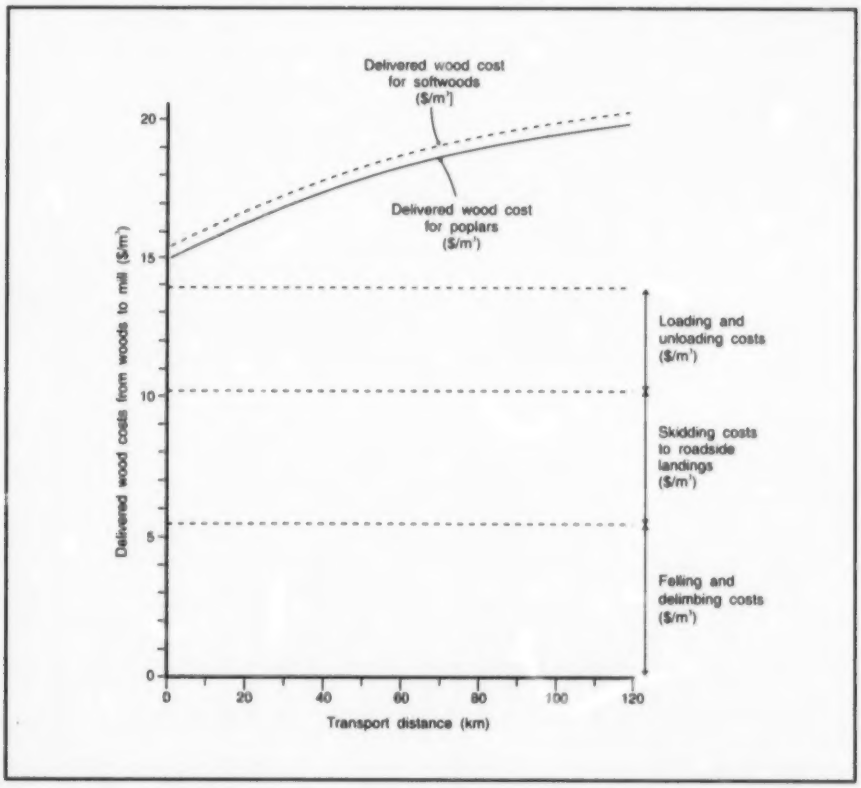

Figure 5. Delivered wood costs for poplar and softwood logs in the Edson, Grande Prairie, and Slave Lake regions of Alberta, 1987.

Table 11. Capital and operating costs for 15 nonintegrated and energy-integrated mills producing poplar products[a]

Option	Mill: Product	Mill: Annual production	Energy plant[b]	Electric power sold (megawatt hour/yr)	Unit	Unit wood cost	Electric power purchased	Fuel	Operating, maintenance, & supplies
Nonintegrated plants									
1	Dimension lumber	100 MM fbm	–[c]	–	$/M fbm	103.40	8.87	5.88	12.03
2	Dimension lumber	150 MM fbm	–	–	$/M fbm	103.40	8.73	5.88	12.03
3	Stud lumber	100 MM fbm	–	–	$/M fbm	103.40	5.43	5.88	12.03
4	Stud lumber	150 MM fbm	–	–	$/M fbm	103.40	4.71	5.88	12.03
5	Waferboard (3/8-in.)	150 MM sq. ft.	–	–	$/M sq. ft.	36.50	9.73	11.32	10.69
6	Oriented strand board (3/8-in.)[d]	150 MM sq. ft.	–	–	$/M sq. ft.	36.50	9.73	11.32	10.69
7	Veneer (1/16-in.)	150 MM sq. ft.	–	–	$/M sq. ft.	12.17	0.94	0.83	2.20
Integrated plants									
8	Stud lumber	150 MM fbm	Boiler/TG	0	$/M fbm	103.40	–	0.83	13.53
9	Stud lumber	150 MM fbm	Boiler/TG	329 000	$/M fbm	103.40	–	8.38	17.87
10	Stud lumber	150 MM fbm	Gasifier/DEG	0	$/M fbm	103.40	–	0.73	13.50
11	Stud lumber	150 MM fbm	Gasifier/DEG	346 000	$/M fbm	103.40	–	1.37	22.35
12	Waferboard (3/8-in.)	150 MM sq. ft.	Boiler/TG	0	$/M sq. ft.	36.50	1.57	8.31	11.56
13	Waferboard (3/8-in.)	150 MM sq. ft.	Gasifier/DEG	0	$/M sq. ft.	36.50	–[e]	6.41	12.07
14	Waferboard (3/8-in.)	150 MM sq. ft.	Gasifier/DEG	6 000	$/M sq. ft.	36.50	–	7.66	12.07
15	Oriented strand board (3/8-in.)[d]	150 MM sq. ft.	Gasifier/DEG	6 000	$/M sq. ft.	36.50	–	7.66	12.07

Table 11. Capital and operating costs for 15 nonintegrated and energy-integrated mills producing poplar products[a] (concluded)

Option	Product	Waxes and resins	Labor	General	Contingencies	Total milling	Total unit cost	Total annual cost ($ millions)	Capital cost ($ millions)
Nonintegrated plants									
1	Dimension lumber	–	39.45	6.25	7.25	79.73	183.13	18.3	32.1
2	Dimension lumber	–	35.35	5.47	6.75	74.23	177.63	26.6	45.4
3	Stud lumber	–	23.18	4.50	5.10	56.12	159.52	16.0	20.6
4	Stud lumber	–	22.40	3.80	4.88	53.70	157.10	23.5	27.8
5	Waferboard (3/8-in.)	30.18	27.19	6.07	9.52	104.70	141.20	21.2	52.0
6	Oriented strand board (3/8-in.)[d]	30.18	27.19	6.07	9.52	104.70	141.20	21.2	55.0
7	Veneer (1/16-in.)	–	5.81	0.87	1.03	11.68	23.85	3.6	6.5
Integrated plants									
8	Stud lumber	–	25.03	5.20	4.47	49.06	152.46	22.9	38.9
9	Stud lumber	–	25.03	10.27	6.13	67.68	171.08	25.7	92.9
10	Stud lumber	–	25.43	5.30	4.50	49.46	152.86	22.9	40.5
11	Stud lumber	–	25.43	10.50	5.96	65.61	169.01	25.4	95.3
12	Waferboard (3/8-in.)	30.18	29.53	6.87	8.80	96.82	133.32	25.4	61.2
13	Waferboard (3/8-in.)	30.18	29.86	7.53	8.60	94.85	131.35	20.0	63.6
14	Waferboard (3/8-in.)	30.18	29.86	7.53	8.70	96.00	132.50	20.0	63.6
15	Oriented strand board (3/8-in.)[d]	30.18	29.86	7.53	8.70	96.00	132.50	20.0	67.0

[a] Source: Woodland Resource Services Ltd., Edmonton, Alberta, 1982.
[b] TG = turbogenerator; DEG = diesel engine generator.
[c] Not applicable.
[d] Survey of logging and mill operators and contractors and mill equipment suppliers in July 1986.
[e] Not available.
NOTE: Refer to Table 11 on previous page for annual production of mill products, if required.

end product required. For example, veneer and stud logs are bucked to 2.6-m lengths, but then the veneer logs are further debarked and steamed in steam-conditioning chests. The 1987 average costs for the premanufacture processing of logs were about $\$10/m^3$ for dimension and stud mills and about $\$14–15/m^3$ for a veneer mill. Waferizing for OSB and waferboard, and chipping energy residues cost about $14 per ovendried tonne (equivalent to $\$4.95/m^3$).

Operating costs for the manufacturing process included cost of materials (waxes, resins), fuel and power, repairs, maintenance and contingencies, and labor (Table 11). These costs varied by mill type and were 10–15% higher for a dimension mill than for a stud mill. The costs were also about 5% higher for OSB than for waferboard. Manufacturing costs were about 20% higher for a stud mill utilizing all residues in an energy generator (Option 11) than for the same mill using purchased energy.

Manufacturing operating costs varied by a plant's requirement of logs to manufacture a unit of final product. For example, 5.66 m^3 of poplar logs were needed for 1 M fbm of lumber, 0.67 m^3 of peeler logs for recovery of 1 M sq. ft. of veneer, and 0.5 m^3 and 0.6 m^3, respectively, for recovery of 1 M sq. ft. for waferboard and OSB.

CONVERSION OF LOGGING AND MILL RESIDUES TO ENERGY

Logging residues are the tops and limbs normally left behind in the stand after usable timber is removed. Mill residues include bark, sawdust, shavings, sander dust, veneer trim, slabs and edgings, and any other material not converted into a useful product. The heating value of poplar logging and mill residues depends on their particle size, species, and moisture content, and the type of energy conversion system. The energy conversion systems and their function and output are described in Appendix 2.

Heating Value of Mill Residues

Composition affects the gross heating value (GHV) of residues; for example, aspen bark has a GHV of 20 470 kilojoules per kilogram (kJ/kg), and sound aspen wood has a value of 19 350 kJ/kg (Sofer and Zabrosky 1981). Woodland Resource Services (1982) reported that in this study the bark was 16.5% of log volume and 25% of branch and top volume, of which 40% was lost in logging and transport. The makeup of these residues produced a GHV of about 19 540 kJ/kg. The GHV of aspen logs (especially in old stands), however, is further lowered by advanced decay (Salmi 1964); adjusting the figures to allow for decay in old stands lowered the GHV by 3% to 18 950 kJ/kg.

The moisture content (%) of aspen residues varied by stand maturity as follows:

	Old	Mature	Young
Logs	82	82	104
Sawdust	83	83	105
Planer shavings	60	65	60

Because of heat loss due to the evaporation of excess moisture from burning fresh chips, the GHV was further adjusted for moisture content and lowered by 5% to 18 100 kJ/kg.

The output of an energy conversion system depends on conversion efficiency. Given a GHV of 18 100 kJ/kg, a gasifier with 75% efficiency would yield 13.6 gigajoules (GJ) of gas per ovendried tonne of gasified wood; however, approximately 30% of the heat available in the gas is lost through diesel engine cooling water and as exhaust gases from the engines. Approximately 10.2 GJ therefore remains available as useful energy per ovendried tonne of gasified residue, compared to 11.2 GJ remaining as an output of steam per ovendried tonne of residue used in a boiler. Whether steam generation is more efficient than gasification depends on the demand for steam heat and on the electric power supplied by the energy plant.

Capital Costs for Integrated Energy Residue Conversion Plants

The capital costs for the integrated mills with the smaller boiler/turbogenerator plants are based

on the capital costs for equipment from existing similar mills and on quotes from suppliers (Table 12). Only limited information is available on the gasifier/diesel engine generator plants and the large boiler/turbogenerator plants; therefore these estimates should be viewed as best approximations (B.H. Levelton and Associates Ltd. 1981). For types, descriptions, and outputs of various wood residue energy conversion systems, see Appendix 2.

Table 12. Additional capital costs for an integrated energy residue conversion plant

Option	Wood product plant	Energy plant[a]	Additional capital cost ($ million)
9	150 MM (million) fbm stud mill	Boiler/TG	65.1
11	150 MM fbm stud mill	Gasifier/DEG	67.5
14	150 MM sq. ft. (3/8-in.) waferboard mill	Gasifier/DEG	11.6

[a] TG = turbogenerator; DEG = diesel engine generator.

The capital cost of a stud mill integrated with an energy generation plant with a boiler/turbogenerator is slightly lower than that of a plant with a gasifier/diesel engine generator. Among waferboard mills, only Option 14 was studied in detail (a gasifier/diesel engine generator plant capable of generating surplus power for sale).

Utilization of Wood Residues and Marketing of Energy from Power Generating Plants

Electricity generated from aspen wood residues in Alberta is classified as "reserve power". In 1987–90 it was priced at $0.010 to $0.015 per kilowatt hour (kW·h) and would have been competing with "offset power" priced at $0.05 per kilowatt hour. In the Alberta market, with a sufficient supply of offset power available, an additional supply of reserve power tends to be underpriced. The use of poplar nonmerchantable material and mill residues for energy production increases poplar utilization, but frequently decreases the overall profitability of an energy-integrated mill (Fig. 6). For other sources of electric power available in Alberta and their prices, see Appendix 3.

Options 1 to 7 were single-product mills utilizing purchased energy. To assess the profitability of integrating energy generation plants with stud, waferboard and OSB mills, the following eight options were analyzed:

Option 8: 150 MM fbm stud mill with a 50-megawatt (MW) boiler/turbogenerator steam plant that has a capacity of 42 tonnes per hour (t/h). The steam plant provides electricity and heat for the internal demands of the stud mill; however, only 12% of the available residues are utilized.

Option 9: 150 MM fbm stud mill with a 250 MW boiler/turbogenerator steam plant that has a capacity of 258 t/h. The steam plant provides electricity and heat for sale and for the internal demands of the stud mill. All available residue is utilized, producing 329 000 megawatt hours of electric power for sale[3].

Option 10: 150 MM fbm stud mill with a 6 MW diesel generator and a gasification plant that has a capacity of 84 gigajoules per hour (GJ/h) and produces sufficient electricity to operate the stud mill, but utilizes only 10% of available residues.

Option 11: 150 MM fbm stud mill with a 50 MW diesel generator and a gasification plant that has a capacity of 790 GJ/h and produces 346 000 megawatt hours per year. All available residues are gasified, and surplus electricity is sold.

Option 12: 150 MM sq. ft. (3/8-in.) waferboard mill with 6 MW boiler/turbogenerator steam plant that has a capacity of 35 t/h. The mill uses some available residues for generation of electricity, but still requires purchased energy of 5600 megawatt hours per year.

[3] Personal communication from B. Levelton of B.H. Levelton and Associates Ltd., Vancouver, B.C., July 1987.

Figue 6. Poplar nonmerchantable material and mill residues used for energy production.

Option 13: 150 MM sq. ft. (3/8-in.) waferboard mill with a 6 MW diesel generator and a gasification plant that has a capacity of 84 GJ/h. The power plant contributes to the electricity required by the waferboard mill, which uses all available residues in generating 38 000 megawatt hours per year but still requires purchased energy.

Option 14: 150 MM sq. ft. (3/8-in.) waferboard mill with a 6 MW diesel generator and a gasification plant that has a capacity of 84 GJ/h. All available residues are used, and 6210 megawatt hours of surplus electricity are sold annually.

Option 15: 150 MM sq. ft. (3/8-in.) OSB mill with a 6 MW diesel generator and a gasification plant that has a capacity of 84 GJ/h. All available residues are used, and 6210 megawatt hours of surplus electricity are sold annually.

Comparison of Energy and Labor Needs for Integrated Options

A waferboard mill uses more heat and electric power per unit of processed logs than do dimension and stud mills (Options 1 to 5). On the other hand, a waferboard mill produces much less wood residue per unit of processed logs than the lumber operation.

Stud mills integrated with energy generation plants are poor users of residues. For example, a stud mill integrated with a boiler/turbogenerator steam plant (Option 8) can generate all its electric power needs and reduce fuel purchases by 86% when using only 12% of the residues. Fuel purchases can be reduced 90% by utilizing 10% of wood residues in a stud mill integrated with the gasifier/diesel generator. On the other hand, a waferboard mill (Option 12) with a boiler/turbogenerator steam plant can only generate 85% of its electric power needs and requires additional fuel purchases. The recovered energy is greater in a waferboard mill integrated with a gasifier/diesel engine generator (Option 13) and the heat needed for power generation is the same (84 GJ per megawatt hour) as for another waferboard mill integrated with a gasifier/diesel engine generator (84 GJ per megawatt hour) (Option 14). The latter, however, is self-sufficient in electricity, and fuel purchases are reduced by 36%.

In order to utilize all residues in a stud mill, nearly 90% of the residues would have to be converted to electric power for sale. A gasifier/diesel engine generator plant (Option 11) can produce about 5% more electric power for sale than a boiler/turbogenerator steam plant (Option 9).

A waferboard mill that is integrated with a gasifier/diesel engine generator (Option 14) can generate surplus power for sale, instead of using energy supplied from purchased fuel. When interpreting the output of large gasifier/diesel engine generator plants and boiler/turbogenerator steam plants it is necessary to recognize that their integration into the operation of large stud mills has been limited.

The number of employees needed varies according to the type of mill. A nonintegrated 150 MM fbm dimension mill requires the largest labor force of 183 workers, while a waferboard mill integrated with a gasifier/diesel engine generator employs 159 workers. A stud mill of the same size requires 36% fewer workers, because the mill has fewer machines, fewer end products, and requires less manual sorting than a dimension lumber mill. About 14 more workers are employed in stud mills

integrated with boiler/turbogenerator steam plants or gasifier/diesel engine generators (Table 13). For a waferboard mill with a boiler fired by natural gas (Option 5) only 9 workers are added if a wood-fired boiler/turbogenerator steam plant is installed (Option 12), whereas 11 workers are added if a diesel generator and gasification plant are installed (Options 13 and 14).

ECONOMICS OF POPLAR UTILIZATION OPTIONS

Analyses of the 15 options for industrial utilization of poplar were conducted. All expenditures, such as capital costs of buildings and plant machinery and operating costs (Table 11) were compared with potential product prices (Table 14) and revenues (Table 15) for the first 10 years of operation to determine potential financial returns on invested capital and the potential risk associated with these investments. Internal rates of return (IRR) were calculated for the seven nonintegrated options (Options 1–7) using purchased energy. Returns were calculated for the eight integrated options (Options 8–15) in which the energy required to operate the mills was generated from available mill residues by energy generation plants at the mills. In order to calculate IRR, detailed income/expenditure statements were prepared for each option based on some key assumptions (Table 16).

Financial Returns

The highest IRR among nonintegrated mills was for an OSB mill at 12.2%, followed by a waferboard mill at 4.6% (Table 17). The IRR among energy-integrated mills was highest for an OSB mill integrated with a diesel generator and gasification plant at 10.5%, followed by a waferboard mill with a diesel generator and gasification plant that had surplus power for sale at 5.0%, a waferboard mill with a diesel generator and gasification plant at 4.7%, and a waferboard mill with a boiler/turbogenerator steam plant at 3.8%.

The IRRs were negative for nonintegrated and energy-integrated dimension and stud mills, from –9.9 to –17.5% (Table 17). A nonintegrated veneer mill also had a negative return.

Stud mills were relatively more profitable to operate than dimension mills because of higher revenue from the products. A stud mill with capacity of 150 MM fbm was more profitable to operate than a stud mill with a capacity of 100 MM fbm, while the opposite was true for dimension mills. Veneer and plywood mills were the least profitable to operate because of the high capital costs of plant and equipment, high start-up costs, low recovery of veneer, and a low market price for aspen plywood. The waferboard and stud mills integrated with gasifiers and diesel engine generator plants were more profitable to operate than the same mills integrated with boiler/turbogenerator steam plants.

Sensitivity Analyses

Financial returns from the options studied cannot be considered in isolation from other variables because of the potential uncertainty and riskiness of investment in a poplar wood product plant. Sensitivity analyses were done on key variables to determine the effect that changes in them would have on nonintegrated OSB and waferboard options (Table 18). The variables analyzed were decreasing of product market prices by 10%, increasing of milling costs by 10%, changes in interest rates, changes in the exchange rate of the Canadian dollar, and reduction in mill output.

The IRR declined from 12.2 to 10.5% when a 10% reduction was introduced in the market price of products from a nonintegrated OSB mill (Table 18). The reduction in market price by 10% for a waferboard mill resulted in a decline of IRR from 4.6 to 0.4%.

Increasing the manufacturing (milling) costs by 10% reduced the IRR from 12.2 to 9.7% for an OSB mill and from 4.6 to 0.5% for a waferboard mill, because waferboard manufacturing is more sensitive to rising manufacturing costs than OSB (Table 18). This analysis assumed an interest rate of 13% on construction and 12% on operating capital.

A decline of the interest rate by 1¼% for capital increased the profitability of an OSB mill by 2%, but an increase reduced IRR by the same amount. The decrease in the interest rate on borrowed capital to

Table 13. Wood inputs, energy, and labor requirements for 15 nonintegrated and energy-integrated mills producing poplar products

Option	Wood products plant: Product	Wood products plant: Annual production	Energy plant[a]	Wood consumed (m^3/yr)	Heat from purchased fuel (GJ/yr)	Electric power purchased (megawatt hour/yr)
Nonintegrated plants						
1	Dimension lumber	100 MM fbm	–[b]	567 000	248 000	21 000
2	Dimension lumber	150 MM fbm	–	850 000	372 000	31 000
3	Stud lumber	100 MM fbm	–	567 000	248 000	13 000
4	Stud lumber	150 MM fbm	–	850 000	372 000	17 000
5	Waferboard (3/8-in.)	150 MM sq. ft.	–	300 000	716 000	35 000
6	Oriented strand board (3/8-in.)[c]	150 MM sq. ft.	–	300 000	716 000	35 000
7	Veneer (1/16-in.)	150 MM sq. ft.	–	100 000	50 000	3 000
Integrated plants						
8	Stud lumber	150 MM fbm	Boiler/TG	850 000	52 000	0
9	Stud lumber	150 MM fbm	Boiler/TD	850 000	530 000	0
10	Stud lumber	150 MM fbm	Gasifier/DEG	850 000	39 000	0
11	Stud lumber	150 MM fbm	Gasifier/DEG	850 000	408 000	0
12	Waferboard (3/8-in.)	150 MM sq. ft.	Boiler/TG	300 000	526 000	5 600
13	Waferboard (3/8-in.)	150 MM sq. ft.	Gasifier/DEG	300 000	456 000	–[d]
14	Waferboard (3/8-in.)	150 MM sq. ft.	Gasifier/DEG	300 000	477 000	0
15	Oriented strand board (3/8-in.)[c]	150 MM sq. ft.	Gasifier/DEG	300 000	477 000	0

Table 13. Wood inputs, energy, and labor requirements for 15 nonintegrated and energy-integrated mills producing poplar products (concluded)

Option	Product	Electric power generated (megawatt hour/yr)	Electric power sold (megawatt hour/yr)	Residues (ovendried t/yr)		Number of employees
				Produced	Used by plant	
Nonintegrated plants						
1	Dimension lumber	–	–	255 000	–	136
2	Dimension lumber	–	–	383 000	–	183
3	Stud lumber	–	–	255 000	–	80
4	Stud lumber	–	–	383 000	–	116
5	Waferboard (3/8-in.)	–	–	43 000	–	148
6	Oriented strand board (3/8-in.)[c]	–	–	43 000	–	148
7	Veneer (1/16-in.)	–	–	49 000	–	27
Integrated plants						
8	Stud lumber	19 000	0	383 000	45 000	129
9	Stud lumber	384 000	329 000	383 000	383 000	129
10	Stud lumber	23 000	0	383 000	37 000	131
11	Stud lumber	401 000	346 000	383 000	383 000	131
12	Waferboard (3/8-in.)	33 000	0	43 000	43 000	157
13	Waferboard (3/8-in.)	38 000	0	43 000	43 000	159
14	Waferboard (3/8-in.)	44 000	6 000	43 000	43 000	159
15	Oriented strand board (3/8-in.)[c]	44 000	6 000	43 000	43 000	159

[a] TG = turbogenerator; DEG = diesel engine generator.
[b] Not applicable.
[c] Survey of logging and mill operators and contractors and mill equipment suppliers in July 1986.
[d] Not available.

Table 14. Average annual f.o.b.[a] mill prices of spruce-pine-fir and poplar wood products for 1981-90 and predictions for 1991-93 (in Canadian $)

Year	Exchange value of U.S. $ (Cdn. $)	Standard 2 × 4 in. framing lumber ($/M fbm)		Stud lumber ($/M fbm)		Plywood, 3/8-in. ($/M sq. ft.)		Aspen waferboard, 3/8-in.[d] ($/M sq. ft.)	Aspen oriented strand board, 3/8-in.[d] ($/M sq. ft.)
		Spruce-pine-fir	Poplar[b] (15% discount)	Spruce-pine-fir	Poplar[b] (15% discount)	Spruce-pine-fir[c]	Poplar[b] (15% discount)		
1981[e]	1.1693	182	155	168	142	234	199	181	183[f]
1982[e]	1.2100	171	145	145	123	190	162	165	167[f]
1983[e]	1.2344	230	196	218	185	224	190	184	185[f]
1984[g]	1.2910	199	169	179	152	206	175	175	181
1985[g]	1.3620	208	177	189	161	230	196	197	211
1986[g]	1.4340	257[h]	218	210[h]	179	290	247	208	220
1987[g]	1.3400	268[h]	228	216[h]	184	315	268	184	196
1988[i]	1.3300	247[h]	210	227[h]	193	273	232	158	169
1989[i]	1.3260	245[h]	208	247[h]	210	302	257	221	231
1990[i]	1.1680	217[h]	184	202[h]	172	246	209	154	154
Forecast									
1991[i]	1.1420	211[h]	179	192[h]	163	228	194	148	148
1992[i]	1.1420	217[h]	184	206[h]	175	240	204	166	166
1993[i]	1.1420	228[h]	194	215[h]	183	257	218	183	183

[a] f.o.b. = free on board (i.e., transport costs not included).
[b] Poplar price obtained by discounting of spruce-pine-fir products.
[c] 20% flat tariff when exporting plywood to the U.S. not deducted.
[d] Net prices f.o.b. mill after deduction of export tax of 7.8% in 1986 and 4.0% in 1987 and later.
[e] Source: Widman Management Ltd., Vancouver, B.C., March 1986.
[f] Source: Personal communication from J. Krantz, Minnesota Ministry of Natural Resources, June 1986.
[g] Source: Random Length Publications Inc., Eugene, Oregon, 1981-91.
[h] Net price f.o.b. mill after deduction of 15% export tax.
[i] Source: Personal communication from R. Westergaard, Widman Management Ltd., Vancouver, B.C., February 1991.

Table 15. Projected profit and loss statement (in MM $) for 15 nonintegrated and energy-integrated mills producing poplar products for the first 20 years of operation

Mill (option) costs	Dimension lumber (1) 100 MM fbm	Dimension lumber (2) 150 MM fbm	Stud lumber (3) 100 MM fbm	Stud lumber (4) 150 MM fbm	(5) Waferboard	(6) Oriented strand board	(7) Veneer
Sales revenue[d]							
From product	26.8	40.2	25.0	37.5	32.3	35.9	3.1
Electric power	–[e]	–	–	–	–	–	–
Total	26.8	40.2	25.0	37.5	32.3	35.9	3.1
Cost of sales	17.7	25.8	15.4	22.7	20.4	21.4	3.4
Gross margin	9.1	14.4	9.6	14.8	11.9	14.5	(0.3)[f]
Deductions							
Interest expense							
Operating loan	1.0	1.3	0.9	1.3	0.7	0.7	0.1
Long-term debt	1.8	2.6	1.2	1.6	2.9	2.9	0.4
Subtotal	2.8	3.9	2.1	2.9	3.6	3.6	0.5
Depreciation & amortization	2.7	3.8	1.7	2.3	4.2	4.2	0.6
Total deductions	5.5	7.7	3.8	5.2	7.8	7.8	1.1
Income before taxes	3.6	6.7	5.8	9.6	4.1	6.7	(1.4)[f]
Income taxes							
Payable	1.0	2.1	2.1	3.6	0.8	0.8	–
Deferred	0.6	0.8	0.4	0.5	0.9	0.9	–
Total	1.6	2.9	2.5	4.1	1.7	1.7	–
Net income	2.0	3.8	3.3	5.5	2.4	5.0	(1.4)[f]

Table 15. Projected profit and loss statement (in MM $) for 15 nonintegrated and energy-integrated mills producing poplar products for the first 20 years of operation (concluded)

Mill (option) costs	Stud lumber				Waferboard			Oriented strand board[c]
	(8) Boiler/TG[a]	(9) Boiler/TG	(10) Gasifier/ DEG[b]	(11) Gasifier/ DEG	(12) Boiler/TG	(13) Gasifier/ DEG	(14) Gasifier/ DEG	(15) Gasifier/ DEG
Sales revenue[d]								
From product	37.5	37.5	37.5	37.5	32.3	32.3	32.3	35.9
Electric power	–[e]	4.0	–	4.2	–	–	0.1	0.1
Total	37.5	41.5	37.5	41.7	32.3	32.3	32.4	36.0
Cost of sales	22.0	24.8	22.0	24.5	19.3	19.0	19.2	20.1
Gross margin	15.5	16.7	15.5	17.2	13.0	13.3	13.2	15.9
Deductions								
Interest expense								
Operating loan	1.3	1.3	1.3	1.3	0.5	0.6	0.6	0.6
Long-term debt	2.2	5.3	2.3	5.5	3.5	3.6	3.6	3.6
Subtotal	3.5	6.6	3.6	6.8	4.0	4.2	4.2	4.2
Depreciation & amortization	3.3	7.8	3.4	8.0	5.0	5.2	5.2	5.2
Total deductions	6.8	14.4	7.0	14.8	9.0	9.4	9.4	9.4
Income before taxes	8.7	2.3	8.5	2.4	4.0	3.9	3.8	6.5
Income taxes								
Payable	2.9	0.0	2.8	0.0	0.6	0.5	0.4	0.4
Deferred	0.8	1.0	0.8	1.1	1.1	1.2	1.2	1.2
Total	3.7	1.0	3.6	1.1	1.7	1.7	1.6	1.6
Net income	5.0	1.3	4.9	1.3	2.3	2.2	2.2	4.9

[a] TG = turbogenerator.
[b] DEG = diesel engine generator.
[c] Profit-loss statement for first 10 years of operation.
[d] Sales revenue for OSB unadjusted for price changes (increase) of the product in 1987 and projected changes in 1988-91.
[e] Not applicable.
[f] Negative value.

10% for an OSB mill increased its profitability to as much as 15.5%. Because two-thirds of OSB and waferboard products are sold in the United States, a change in exchange rates affected the volume of sales, and thus profitability. This analysis assumed an exchange rate of $1.00 U.S. = $0.72 Canadian. An appreciation in the value of the Canadian dollar by $0.05 would have reduced American demand for OSB and waferboard (in this analysis it was assumed that demand remained unchanged) and it reduced profitability in the analysis by 0.5 and 4.0% for OSB and waferboard mills, respectively. The reduction of output resulting from lower demand for these products lowered IRR and profitability.

Table 16. Key assumptions for calculations of capital expenditures, operating revenues, and rates of return

Construction loan: 13% for 3 years	
Capital cost of plant: 13% for 5 years	
Operating costs: 12% for 5 years	
Construction period: 3 years	
Terms of loan repayment: declining balance	
Escalation of operating revenues and costs: none	
Nominal engineered production capacity used:	1-year: 65%
	2-year: 90%
	3-year: 100%
Depreciation and amortization:	building and machinery straight line 15 years
	mobile equipment straight line 5 years
Income tax: 43% of taxable income	
Exchange rate (value): $1.00 U.S. = $0.72 Canadian	

Financial and Earning Projections

Future earnings of plants depend on the utilization of plant capacity, the price for wood products, delivered wood and manufacturing costs, and other factors. Future earnings calculations for each option assumed that the plants in this study were operating at full capacity by the 3rd year of operation and that sales lagged behind production as product inventories were built up during the lst year. Revenues from the sale of electric power were based on a price of $0.0125 per kW·h for reserve power. Details of projected revenues and costs for the 15 mill options are shown in a profit/loss statement for 20 years of operation (Table 15). Costs of sales were based on the manufacturing costs adjusted for changes in inventory and productivity.

Capital cost allowances used in calculating taxable income were based on the Income Tax Act regulations and amendments for investment income, dated February 26, 1986, which allow only 50% of the capital cost allowance to be used in the year of acquisition (known as the half-year rule)[4].

Cash flow calculations and projections indicated that a nonintegrated OSB mill generated the highest net income on equity capital invested, followed by a nonintegrated waferboard mill; purchasing energy for these mills proved cheaper than generating it. Costs exceeded revenues in stud and dimension mills and in veneer and plywood plants.

Cash flow calculations and projections also indicated that an energy residue conversion plant integrated with an OSB mill increased the gross total revenue, but this increase was not high enough to offset the higher costs of interest and depreciation, and it resulted in lower net income. A comparison of Options 9 and 11 with Option 4 in Table 15 shows that the utilization of all stud mill residues to generate electric power for sale substantially lowered the net revenue and income. Additional revenue generated by the sale of power in an energy-integrated waferboard mill made it more profitable than the nonintegrated waferboard mill.

[4] Personal communication from K.E. King, Chartered Accountant, of Kenneth E. King Professional Corporation, Edmonton, Alberta, November 1987.

Table 17. Internal rate of return for 15 nonintegrated and energy-integrated mills producing poplar products

Option	Mill: Product	Mill: Annual production	Energy plant[a]	Internal rate of return (%)
Nonintegrated plants				
6	Oriented strand board	150 MM sq. ft.	–	12.2
5	Waferboard	150 MM sq. ft.	–	4.6
4	Stud lumber	150 MM fbm	–	-10.2
3	Stud lumber	100 MM fbm	–	-15.2
1	Dimension lumber	100 MM fbm	–	-16.8
2	Dimension lumber	150 MM fbm	–	-12.4
7	Veneer	150 MM sq. ft.	–	No net revenue
Integrated plants				
15	Oriented strand board	150 MM sq. ft.	Gasifier/DEG	10.5
14	Waferboard	150 MM sq. ft.	Gasifier/DEG	5.0
13	Waferboard	150 MM sq. ft.	Gasifier/DEG	4.7
12	Waferboard	150 MM sq. ft.	Boiler/TG	3.8
10	Stud lumber	150 MM fbm	Gasifier/DEG	-9.9
8	Stud lumber	150 MM fbm	Boiler/TG	-10.4
11	Stud lumber	150 MM fbm	Gasifier/DEG	-11.1
9	Stud lumber	150 MM fbm	Boiler/TG	-17.5

[a] DEG = diesel engine generator; TG = turbogenerator.

Table 18. Sensitivity analysis of internal rate of return to changes in manufacturing costs and exchange rates for a nonintegrated oriented strand board mill and a waferboard mill

Mill	Basic study[a]	Sale price cut by 10%	Manufacturing cost increased 10%	Exchange rate value[b] of Canadian $ increased by $0.05
Oriented strand board mill				
Sales revenue (in nominal $)	392 951	353 656	392 951	380 180
Manufacturing cost (in nominal $)	213 912	213 912	236 204	213 912
Internal rate of return (%)	12.2	10.5	9.7	11.7
Waferboard mill				
Sales revenue (in nominal $)	293 838	264 455	293 838	272 838
Manufacturing cost (in nominal $)	203 783	203 783	224 161	203 783
Internal rate of return (%)	4.6	0.4	0.5	0.6

[a] Assumes $1.00 U.S. = $0.72 Canadian.
[b] Assumes 65% export of waferboard and oriented strand board to the U.S.

Investment Requirements and Sources

Financing of mill operations includes the capital investment in the building plant, machinery, and equipment, interest on the construction loan, preoperating expenses (e.g., log inventories and supplies, prepaid items such as property taxes and insurance), and initial operating capital. To finance poplar product manufacturing, both equity and borrowed capital are required. Table 19 shows the total investment required for mill start-up, and the equity and borrowed capital required to finance investment for each alternative. Two-thirds of the capital is usually borrowed, while one-third and the interest on the construction loan and initial working capital are financed from private equity capital. The construction loan usually has higher interest costs and is due within the 3rd year of operation. Preoperating expenses can be high, because an 8-month volume of log inventory must be at the mill yard at the beginning of spring breakup in April (this is enough to enable milling operations to continue until the start of the next winter logging season in December). Following the start-up of a mill, the debt load can be financed jointly from accounts receivable and from funds borrowed from the bank.

Before investing equity capital in the manufacture of poplar wood products, equity capital investors expect returns of 10–20%. Financial institutions such as chartered banks may be willing to finance poplar product manufacturing for prospective qualified investors. They may also require loan guarantees for lending capital to a higher risk business or may charge higher interest to investors with low start-up cash capital.

In order to attract in attracting private equity capital to this industry, some form of government assistance and incentive programs may be required to compensate for perceived lower returns and associated risk. In the interim, governments have several ways to encourage investment by private equity capital in poplar product manufacturing. They can provide either capital development grants, low interest or interest-free loans, loan guarantees, or debentures. Another effective incentive can be investment tax credits of 5–10% and/or a government guarantee for a mill up to the first 15 years of operation.

SUMMARY

This study proved that poplar harvesting in the Slave Lake region of Alberta can be done efficiently during the winter months, although cold weather (–30°C) may reduce harvest productivity and timber recovery when chain saws are used. Mechanized harvesting with machines capable of cushioning a tree's fall would have minimized the breakage of tops and branches. This breakage is more common in cold weather and creates a hazard to loggers.

Productivity for tree-length and whole-tree poplar logging was high in mature and old stands with large trees. Whole-tree logging increased felling, skidding, and loading costs, but the cost of hauling remained unchanged. A Prentice heel-boom loader was very effective for loading larger logs. Loading logs of variable lengths and smaller diameters did not affect loading productivity. Although not used in this trial, the feller–buncher would have been more effective in the harvesting of smaller trees and would have assisted in improving grapple–skidder productivity.

The recovery of dimension lumber and studs from poplar logs was about one-half the recovery of the same products from softwoods, while veneer recovery from poplar was about 5% of the total log volume. Recovery of dimension lumber and studs combined for standard construction grade was 53, 49, and 45% for mature, old, and young stands, respectively, which is substantially lower than the 93% average recovery for SPF from old stands.

Heartrot, crook, and large amounts of mill residues were the main reasons for low poplar lumber recovery. Heartrot was most prevalent in the old stand, while crook and sweep were present in all stands. SPF dimension lumber and stud mills were not well suited for sawing poplars; therefore, the crooked logs were difficult to process through the scrag mill. To buck the crook more efficiently from poplar logs, the log deck should be enlarged and include headrig scanners. The planing of poplar lumber took three times as long as the planing of SPF lumber. Dimension and stud mills were not equipped to handle the large amount of residues

Table 19. Financing investment needed for 15 nonintegrated and energy-integrated mills producing poplar products[a]

Option	Mill: Product	Mill: Annual production	Energy plant	Electric power sold (megawatt hours/yr)	Investment required (MM $): Plant capital	Investment required (MM $): Interest during construction	Investment required (MM $): Working capital	Investment required (MM $): Total	Sources of financing (MM $): Equity	Sources of financing (MM $): Debt	Sources of financing (MM $): Total
Nonintegrated plants											
1	Dimension lumber	100 MM fbm	–[b]	–	32.1	2.7	6.3	41.1	19.6	21.5	41.1
2	Dimension lumber	150 MM fbm	–	–	45.4	3.8	9.2	58.4	28.0	30.4	58.4
3	Stud lumber	100 MM fbm	–	–	20.6	1.7	6.0	28.3	14.5	13.8	28.3
4	Stud lumber	150 MM fbm	–	–	27.8	2.3	8.9	39.0	20.4	18.6	39.0
5	Waferboard	150 MM fbm	–	–	52.0	4.4	4.6	61.0	26.2	33.9	60.1
6	Oriented strand board[c]	150 MM sq. ft.	–	–	55.0	4.4	4.6	64.0	28.6	35.4	64.0
7	Veneer	150 MM fbm	–	–	6.5	0.5	1.2	8.2	3.8	4.4	8.2
Integrated plants											
8	Stud lumber	150 MM fbm	Boiler/TG	0	38.9	3.3	9.1	51.3	25.3	26.0	51.3
9	Stud lumber	150 MM fbm	Boiler/TG	329 000	92.9	7.8	10.0	110.7	48.5	62.2	110.7
10	Stud lumber	150 MM fbm	Gasifier/DEG	0	40.5	3.4	9.1	53.0	25.9	27.1	53.0
11	Stud lumber	150 MM fbm	Gasifier/DEG	346 000	95.3	8.0	10.3	113.6	49.7	63.9	113.6
12	Waferboard	150 MM sq. ft.	Boiler/TG	0	61.2	5.1	4.8	71.1	30.1	41.0	71.1
13	Waferboard	150 MM sq. ft.	Gasifier/DEG	0	63.6	5.3	4.9	73.8	31.2	42.6	73.8
14	Waferboard	150 MM sq. ft.	Gasifier/DEG	6 000	63.6	5.3	4.9	73.8	31.2	42.6	73.8
15	Oriented strand board[c]	150 MM sq. ft.	Gasifier/DEG	6 000	67.0	5.3	4.9	77.2	32.6	44.6	77.2

[a] Source: Woodland Resource Services, Edmonton, Alberta, 1982.
[b] Not applicable.
[c] Personal communications from logging and mill equipment suppliers, 1987.

from the debarking and sawing process, and the planing of lumber.

The IRR, including the capital costs of the mill, was highest (at 12.2%) for an OSB mill that had a capacity of 150 MM sq. ft. and was buying power, followed by an IRR of 10.5% for an OSB mill generating its own power. The IRRs were, respectively, 4.6 and 5.0% for waferboard mills buying or generating their own power.

Ten percent lower product prices for OSB products reduced the IRR by about 2%, while the same drop in price resulted in a 4% decline in the profitability of waferboard mills.

The IRR was 4.7% for a waferboard mill integrated with a diesel generator and gasification plant producing its own energy, but still requiring purchased energy. For a waferboard mill with mainly purchased energy, the IRR was 3.5%.

The present low demand for softwood dimension lumber and studs and veneer appears to be the main reason for the relatively low prices of these products, and for the negative returns for those mills currently producing poplar solid wood products.

ACKNOWLEDGMENTS

Gratitude is expressed to the owners and management personnel of Weldwood of Canada Ltd., Zeidler Forest Industries Ltd., and Vanderwell Contractors Ltd. (all of Slave Lake) for their cooperation in providing confidential information on their operations. Special thanks are due to Woodland Resource Services Ltd. for completing the contractor's report (ENFOR study P-207) and to R.A. Harmer, financial analyst, Stothert Management Limited, Vancouver, for reviewing the financial analyses in this report. Also gratefully acknowledged is the assistance of M. Sharma of the Department of Rural Economy at the University of Alberta in the collection of additional data, data analysis, and verification of results.

REFERENCES

Alberta Energy and Natural Resources. 1979. Alberta scaling manual, chapter II. Forest Management Manual ENR. Alberta Forest Service, Edmonton, Alberta.

Alberta Energy and Natural Resources. 1982. Alberta Phase 3 inventory cover type volume table. Central Alberta volume sampling regions 4, unpublished ENR Report published in 1985 as ENR Report No. 61c.

B.H. Levelton and Associates Ltd. 1981. An evaluation of wood waste energy conversion systems. Environ. Can., Can. For. Serv., Ottawa, Ontario. ENFOR Project C-111. Rep. KL 229-0-4110.

Coban Institute. 1981. Costs of harvesting aspen stands for energy production. Environ. Can., Can. For. Serv., North. For. Res. Cent., Edmonton, Alberta. ENFOR Rep. P-163.

Haygreen, J.D.; Bowyer, J.L. 1982. Forest products and wood science. Iowa State Univ. Press, Ames, Iowa.

Jessome, A.P. 1977. Strength and related properties of wood grown in Canada. Environ. Can., East. For. Prod. Lab., Ottawa, Ontario. For. Tech. Rep. 21.

McIntosh, J.A; Carroll, M.N., eds. 1980. Utilization of western hardwoods. Forintek Can. Corp., West. For. Prod. Lab., Vancouver, B.C. Spec. Publ. SP-2.

Mullins, E.J.; McKnight, T.S., eds. 1981. Canadian woods. Their properties and uses. Univ. Toronto Press, Toronto, Ontario.

Ondro, W.J. 1989. Utilization and market potential of poplar in Alberta. For. Can., North. For. Cent., Edmonton, Alberta. Inf. Rep. NOR-X-305.

Panning, D.J.; Gertjejansen, R.O. 1985. Balsam poplar as a raw material for waferboard. For. Prod. J. 35(5):48–54.

Random Lengths Publications Inc. 1991. Random lengths lumber and plywood market reporting service. Weekly reports on North American forest product marketing for 1981–91.

Salmi, J. 1964. The influence of decay on the calorific value of birch wood. Pien Puir, Tormikum. Julk, Helsinki No. 168.

Sofer, S.S.; Zabrosky, O.R., eds. 1981. Biomass conversion processes for energy and fuels. Plenum Press, New York, N.Y.

Statistics Canada. 1981-91. Canadian forestry statistics, Cat. No. 11-202. Logging, Cat. No. 25-201. Manufacturing industry of Canada, Cat. No. 31-203. Survey of production, Cat. No. 61-202. Ottawa, Ontario.

U.S. Forest Service. 1974. Wood handbook. Wood as an engineering material. U.S. Dep. Agric., For. Serv., For. Prod. Lab., Madison, Wisconsin. Agric. Handbook 72. Revised.

Unpublished reports:

B.H. Levelton and Associates Ltd. 1981. An evaluation of wood waste energy conversion systems. ENFOR Project C-111. Unpublished contractor's report. Prepared for Environ. Can., Can. For. Serv., Pac. For. Res. Cent., Victoria, B.C.

Widman Management Ltd. 1985. Canada's forest industry. Markets '85–88. Vancouver, B.C. Unpublished report.

Widman Management Ltd. 1986. Canada's forest industry. Markets '86–89. Vancouver, B.C. Unpublished report.

Widman Management Ltd. 1987. Canada's forest industry. Markets '87–90. Vancouver, B.C. Unpublished report.

Widman Management Ltd. 1988. Canada's forest industry. Markets '88–92. Vancouver, B.C. Unpublished report.

Widman Management Ltd. 1989. Canada's forest industry. Markets '89–93. Vancouver, B.C. Unpublished report.

Widman Management Ltd. 1990. Markets '90–94. The outlook for North American forest products. Vancouver, B.C. Unpublished report.

Widman Management Ltd. 1991. Markets '91–95. The five-year outlook for North American forest products. Vancouver, B.C. Unpublished report.

Woodbridge, Reed and Associates Ltd. 1985. Utilization of hardwoods in Northern Alberta: Summary report. Prepared for the Northern Alberta Development Council, Peace River, Alberta.

Woodland Resource Services Ltd. 1982. Development of an integrated operation for aspen wood products and energy from aspen biomass. ENFOR Project P-207. Unpublished contractor's report. Prepared for Environ. Can., Can. For. Serv., Ottawa, Ontario.

Zsuffa, L.; Boufford, D.; Leggatt, M.A. 1979. Poplar biomass production and utilization. Environ. Can., Can. For. Serv., Petawawa Natl. For. Inst., Chalk River, Ontario. ENFOR Project P-139. Unpublished report.

APPENDIX 1

SELECTED METRIC (SI) UNITS AND CONVERSION FACTORS[a]

Imperial		Metric (SI)
1 inch (in.)	=	2.54 centimeters (cm)
1 mile	=	1.609 kilometers (km)
1 acre	=	0.405 hectares (ha)
1 cord (85 cu. ft. solid wood)	=	2.407 cubic meters (m^3) coniferous, 2.010 m^3 deciduous
1 cubic foot (cu. ft.)	=	0.028 m^3
1 cunit[b] (100 cu. ft. solid wood)	=	2.832 m^3 (roundwood)
1 ton (2000 lb.)	=	0.907 tonne (t)
1 cord (stacked) per acre	=	8.956 m^3 (stacked) per ha
1000 board feet	=	4.29 m^3 (roundwood)
1 thousand (M) foot board measure (fbm)	=	1.623 m^3 (lumber)
1 bone dry unit (BDU) wood chips (2400 lb.)	=	1090 kilograms (kg)
1 square foot (sq. ft.) of sheet product (1/2-in. basis)	=	1.180 square meters (m^2), on a 1-millimeter (mm) basis
1 sq. ft. of sheet product (1/16-in. basis)	=	0.147 m^2 (1-mm basis)

[a] Source: Environment Canada. 1974. Selected metric (SI) units and conversion factors for Canadian forestry. Environ. Can., Ottawa, Ontario.

[b] 1 cunit (100 cu. ft.) = 660 fbm (roundwood)

WOOD RESIDUE ENERGY CONVERSION SYSTEMS

A number of energy conversion systems have been used for converting wood residue to energy. These generally fall into two broad categories: 1) conventional-fuel steam boilers, and 2) second-generation systems, which produce hot and combustible gases and liquid fuels[1].

Hog-fuel Steam Boilers

Large hog-fuel boilers, common to the forest industry, burn wet or dry fuel with excess combustion air on a fixed or moving grate. The hot gases pass through or around boiler tubes, generating steam that can be converted to heat or used to generate electricity. Boilers vary in capacity from 270 to 11 000 t/h of steam. Designs vary widely from the older dutch oven units in which fuel was burned in a pile to the most recent multiple-fuel, multiple-burning-zone units in which different fuel types are burned in specific areas. Many smaller hog-fuel boilers handle special fuels and range from dry, pulverized fuel units to package boilers capable of handling wet fuel. Typical of the former are the Ray and the Vekoo units that produce 1–9 t/h of steam; the latter are represented by the Wellons Cell with pile burning and the Vyncke boiler with underfire feed. The highest practical steam temperature and pressure are required in the generation of electricity. Large hog-fuel boilers are operated at 6000 kilopascals (kPa), although pressures up to 8000 kPa have been used with special alloy boiler tubes.

Hog-fuel steam boilers are most suitable for operations such as pulp mills, which have a balanced demand for both electrical and thermal energy. Mill residues provide far more energy than is required by sawmills.

Second-generation Systems

Suspension Burners

In these burners, fine wood particles are mixed with air and burned in suspension. The combustion takes place in a special small chamber (Energex) or in the larger firebox of the Coen boiler. The basis of all suspension burners is to make the fuel small and dry enough so that combustion takes place within a small chamber. The size of the chamber controls the maximum moisture and size of the fuel particle. Small chambers (such as the Energex) require less than 15% moisture content and fuel particles smaller than 3.2 mm. Systems with larger chambers (such as the Waycot and G.P. Heat Cell) can burn larger particles with higher moisture. Suspension burners use one of two methods of flame stabilization: either some very hot, radiant refractory is located around the fuel and air feed, or an auxiliary fuel is used continuously.

Suspension burners are relatively inexpensive and can have short pay-back periods when they are used as replacements for fossil-fuel burners. They generate a hot, clean gas that can be used in dry kilns, power boilers, veneer dryers, and other processes. The burners are fully automated and have sufficient output for most applications. One disadvantage of this system is that it requires dry, fine fuel such as planer shavings, but they must be processed by hammer mill to reduce the particle size. Typical manufacturers of suspension burners are Energex Ltd., Waycot Systems Ltd., Coen Company, and Peabody Gordon–Piatt.

Fluid-bed Combustors

Fluid-bed combustors use a fluidized bed, usually sand, to provide a heat reservoir and a turbulent mixing zone for combustion to take place. Fluidization occurs when air is passed through a bed, but as the air volume and velocity increase a point is reached at which the granular material is lifted and the entire mass takes on a boiling appearance. This boiling or fluidization persists over a wide range of air flows, and ultimately, as velocity increases, the granular material is dispersed in the air. Variations in fluid-bed combustors are in the amount of combustion that occurs in and out of the fluid bed. In true fluid beds, such as coal-fired beds, all of the fixed carbon combustion and most of the volatile combustion occur in the bed. The bed is

[1] Much of the content in this appendix was acquired form B.H. Levelton and Associates Ltd., Vancouver, B.C., 1981.

deep, and there is a high pressure drop across the system. Fluid-bed combustors or boilers using coal are true fluid beds. At the other extreme are fluid grates, where only the very largest particles are burned in shallow beds, and there are correspondingly lower pressure drops. Fluid beds offer high heat transfer and combustion rates, which allow for small thermal output units. Fluid-bed boiler systems are also small, compact units because of the excellent bed-to-tube heat transfer coefficients. Although much of the ash is emitted with combustion gases, there may be a need for ash removal from the bottom of the bed.

Fluid-bed combustors represent proven technology, and there are over 40 units with a wide variety of heat loads used in the forest products industry. Typical units are made by Energy Products of Idaho, Combustion Power Co. Inc., and Applied Combustion Systems. The systems may require emission control devices to meet Canadian emission standards.

Multiple-chamber Combustors

Wood residues consist of 70% volatile matter and 30% fixed carbon. Multiple-chamber systems are designed to separate the volatiles from the fixed carbon and to burn them in separate chambers. In the primary chamber, sufficient air is added to gasify the volatiles and provide for the combustion of the char. Because of the low air supply this chamber is quiescent, and very little particulate is carried out. A choke usually separates the primary and secondary chambers. Secondary air is added after the choke to complete the combustion of the produced gas. The temperature in the secondary chamber is usually higher than that in the primary chamber. The amount and location of secondary combustion air and the ability to burn wet fuel are the main criteria for differentiation between single- and multiple-chamber combustors. Multiple-chamber devices will combust wet fuel and will add secondary air some distance from the pile.

Multiple-chamber combustors are proven technology. They have the ability to burn moist fuel in a variety of sizes with low emissions of particulates. Some systems can combust wood residues with a high cull content and municipal refuse. Multiple-chamber combustors are the fastest-growing combustion systems in the forest products industry in Canada. Suppliers are Lamb–Cargate Industries Ltd., Konus Kessel (QM Industries in B.C.), Berg and Starch AB, and Auga and Varma Canada.

Single-chamber Combustors

Single-chamber combustors are the simplest of all combustion systems; fuel and air are mixed and burned in these chambers. Silo burners, teepee burners, most dutch ovens, and most steam boilers are all single-chamber devices. Single-chamber combustors work well when they are small, because it becomes difficult to stabilize the combustion process in large units. The stability problems result from the poor mixing of the overfire air when large distances are involved and from the fact that there is no flame stabilization device (such as reradiating refractory). Particulate emissions are often higher than from other systems. The systems usually have limited turndowns and response to demand loads. The advantages of single-chamber combustors are the simplicity of the units, the low initial cost, and their ability to handle a wide variety of fuels; however, such units do not burn well large loads of fine, dry fuels. Manufacturers are Bigelow–Liptak Corporation, Olivine Corporation, and Rettew Associates Ltd.

Liquid Fuel Production from Wood Residues

The production of liquid fuels from wood residues continues to attract much interest because liquid fuels offer the advantage of being amenable to an existing distribution system, are a product that people are familiar with, and can be easily stored. Four processes are used:

1. Methanol via catalytic reaction of wood gas.

   The production of a synthetic gas from wood and its subsequent conversion to methanol appears to be the most attractive of the liquid fuel alternatives at the present time. The conversion of the synthetic gas to methanol is a well-proven technology that is commercially available from such companies as ICI, Lurgi, and Mitsubishi. In order to produce a synthetic gas, an oxygen-blown gasification system or an advanced pyrolysis system will have to be utilized. Neither of these systems has yet been demonstrated on a scale that would be suitable for a commercial plant.

2. Ethanol via fermentation of treated wood.

   Ethanol from fermentation of pretreated wood using acid hydrolysis to convert cellulose to fermentable sugars has long been known but was too expensive. More recently, steam

hydrolysis and bacterial and fungal treatments have shown considerable promise, not only in decreasing the costs of chemicals but also in producing a variety of alcohols. There are no commercial plants operating in North America.

3. Heavy fuel oil via pyrolysis of wood.

   Heavy fuel oil via pyrolysis has the disadvantage of producing large amounts of liquid, gaseous, and solid products. Without markets for solids and gases the process is usually uneconomical. Little experimentation has been done using this oil as a feedstock for upgrading.

4. Heavy fuel oil via liquefaction of wood.

   The direct liquefaction of wood residues has been developed on a laboratory scale by the U.S. Bureau of Mines, the University of Toronto, the University of Saskatchewan, the British Columbia Research Council, and others. The scale-up from bench apparatus to a plant with a capacity of five barrels per day by the U.S. Bureau of Mines was not successful. This technology does offer high conversion efficiency and is still being actively studied; however, a minimum commercial size of 1000 tonnes per day (t/d) of methanol will be too large for existing forest product operations.

ENERGY SOURCES AND PRICES

There is a demand for additional energy sources; however, their market price is determined on the basis of availability and security of supply. There are currently four categories of purchased electric power in Alberta: offset, emergency, reserve, and firm. Offset power is purchased on an interruptible basis from major synthetic oil refineries in amounts up to 50 MW. Emergency power is also purchased from them, but the electricity is produced from gas turbines. Reserve power is an interruptible electricity source available on a regular basis. Firm power is an uninterruptible electricity source, which can be used by a power company in its regulatory power supply calculation.

The 1987 prices per kilowatt hour for these four categories of power were as follows: offset $0.05; emergency $0.030; reserve $0.010–0.015; and firm $0.015–0.020. Sources: Alberta Power Ltd., 1987, and Northwestern Utilities Ltd., July 1987.